Physical Layer DVB Transmission Optimisation (PLUTO)

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ABSTRACT

The IST project PLUTO will research and develop novel techniques for broadcast transmitter networks that will minimise the complexity and power consumption of end user equipment. These techniques; Transmitter Diversity and Low Cost On-Channel Repeaters will improve reception in areas of poor coverage such as for mobile reception, indoors and sparsely populated or obscured locations. Test service scenarios will be developed to illustrate the benefits of the technology so that effectiveness can be researched in a variety of service and terrain scenarios using purpose built test systems. Currently in-fill transmitters are used to illuminate "black holes" where network broadcast signals cannot penetrate. These transmitters generally use different polarisations and frequency channels to the main transmitters. Low cost on-frequency transmitters, although technically demanding could provide a better way of illuminating "black holes" with minimal complexity and conserving valuable spectrum. PLUTO is an IST STREP project involving nine partners. It started in January 2006 for a duration of 30 months.

I. INTRODUCTION

DVB-T, DVB-H, DAB and DMB [14], [15], [16], [17] are key radio broadcast network technologies which are expected to complement emerging technologies such as WiMAX and its derivatives in future 4G networks. These technologies use Orthogonal Frequency Division Multiplexing (OFDM) to distribute data over a large number of carriers spaced apart at precise frequencies providing frequency diversity.

Complexity and power consumption of personal receiving devices can be optimised by improving the transmission of signals in non line of sight cluttered environments using transmit diversity and low cost repeaters. Transmit diversity exploits the statistical nature of fading due to multipaths and reduces the likelihood of deep fading by providing a diversity of transmit signals; multiple signals are transmitted in such a way as to ensure that several signals reach the receiver each with uncorrelated fading. Resultant digital broadcast networks would have fewer transmitter sites and thus be more cost-effective and have less environmental impact. Transmit diversity is more practical than receive diversity due to the difficulty of locating two receive antennas far enough apart in a small mobile device. Transmit diversity is a commonly used technique for most digital wireless transmission systems and it seems an omission that it has not been applied to the area of digital broadcast services.

Digital broadcast networks are generally being designed by broadcast companies whose previous experience is in providing networks for analogue services. These companies are basing their networks on experience learnt from analogue networks, which are to maximise power, minimise interference and avoid multipaths since this caused ghosting on analogue receivers. These companies are pre-occupied with the challenges of evolving from analogue to digital networks and do not have the effort to invest in technology research. No allowance has currently been made in the Europe for indoor reception or for new applications such as mobile. The fixed networks have been designed assuming that receive antennas are fixed at roof height and the opportunity has not been taken to exploit the ability of OFDM to decode main and multipath signals.

There has been much work published relating to application of transmit diversity for OFDM systems applying the techniques to non-standard implementations or to wireless LAN standards. So far there has been little work published on the application of these techniques for broadcast and no evidence of real world trials, exceptions are [1] and [4] which refer to applicability of the techniques for DVB-T; this project will build on that work. Commonly known techniques are *space-time block codes* (e.g. [9], [10]) or *space-time trellis codes* (e.g. [8]). Both classes of space-time codes, however, are not compatible with standards. Compatible diversity techniques are *delay diversity (DD)*, *cyclic delay diversity (CDD)*, *phase diversity (PD)*, *Doppler diversity(DoD)* – also referred to as *time variant phase diversity(TPD)* in [1] - and *discontinuous Doppler diversity (DDoD)*. These techniques can be applied on top of already existing standards and are applied and investigated in e.g. [1], [4], [6], [12] for OFDM based systems. First considerations of TX delay diversity have been made in [13] for single carrier systems with linear modulation schemes. In [2] these techniques are described as space-time respectively space-frequency codes. All these techniques assume statistically independent fading of multiple Tx/Rx paths.

Competing systems use multiple antennas as parts of an antenna array for *beam-forming*. Both approaches are compared in [11] in terms of channel capacity and FEC capabilities. In spite of the different philosophies, both kinds of antenna techniques can be combined [3]. Using beam-forming typically implies an additional antenna gain and narrows delay and Doppler spread of the channel. This reduces the effect of interferences such as inter symbol interference (ISI) and inter carrier interference (ICI). However, this means concurrently a reduction of diversity. An additional implementation of CDD and DoD as special implementation of frequency respectively time domain diversity techniques re-offers diversity, without implying additional interference impairments into the system [7]. Comparisons for CDD and space-time block coding can be found in [5]. Equipment does not exist on the open market that allows the diversity effects to be generated and measurement metrics have not been defined. Currently broadcasters typically make integrated RF power measurements to evaluate received signal strength in the same way that analogue coverage was measured and this is of limited use for digital broadcast. There are few published measurements [18,19,20] of actual fading in differing scenarios such as mobile, indoors and NLOS or evaluating the relationship between frequency and fading. There has been no published work to date on how seasonal fading affects fixed reception in NLOS for broadcast applications. This project will accumulate and publish measurement data that can be used for future reference.

MultiChannel power amplification (MCPA) systems were first used in satellite transmissions to amplify up-link and down-link constant envelope signals such as FM and QPSK and are now commonly used in 2 and 3G base stations. These systems exploit feed forward analogue broadband linearization. No MCPA products are currently available in the broadcasting domain mainly due to the drawbacks of having non constant envelope signals (OFDM) and huge frequency separation between TV channels (eg UHF over 400 MHz). Recent advances in technology, increasing the power of low cost high speed digital signal processing equipment and novel signal processing algorithms will be exploited to investigate if such a system is now achievable.

An effective echo canceller for this application must have a means of estimating the channel, calculating coefficients and applying corrections quickly enough to cancel rapidly introduced and varying echoes such as would be experienced from aircraft and moving vehicles. Current systems are often based on feedback equalisers, which use an iterative algorithm to estimate the channel. The limitations of this approach are that the response to a time varying channel is very slow, making them unsuitable for next generation networks, and that the system can go unstable under certain conditions. This project will explore some novel and patentable ideas for implementing more rapidly responsive and stable feed-forward algorithms. In this overview paper we present the objectives and the key issues in Section II. Section III describes the test environment for the field trials. This is followed in Section IV, which describes the technological approach of the project. Finally we outline in Section V the potential expected impact on standardisation.

II. OBJECTIVES and KEY ISSUES

The overall objective of this project is to develop network technology and architecture that allows affordable broadband broadcast services to be delivered to European users and particularly in less developed regions. Novel techniques will be researched that will minimise cost of future broadcast networks and minimise the complexity and power consumption of end user equipment. The objectives and the key issues are high lightened in more detail in the following.

i. Transmit Diversity

Transmit Diversity can improve non line of sight reception provided multiple signals are received with decorrelated fading, and that the receiver can effectively process the signals to its advantage. Diversity exploits the statistical nature of fading due to multipaths and reduces the likelihood of deep fading. Uncorrelated fading can be achieved through spatial separation of the transmit antennas and by applying phase effects to the signals that decorrelate them in the time domain.

The measurable objectives of the transmit diversity part of this project are to;

1. Identify what effects must be applied to the transmitted signals to ensure that they are received with uncorrelated fading and how these effects can be generated.
2. Define the relationship between 1 and the reception scenario: mobile, indoors, urban clutter, rural obscuration, and then compile and document extent of fading observed.
3. Confirm that receivers will process the diverse signals.
4. Identify how much diversity gain can be achieved.
5. Identify how the effects can be implemented and produce experimental equipments.
6. Identify how any adverse effects caused by interference between the diverse signals for line of sight reception can be mitigated.
7. Produce experimental equipments suitable for productisation.

ii. Mini On-Channel Echo Cancellers for Repeater

A mini on-channel repeater would be low power low cost stand alone subsystem that could be placed anywhere in a network where it could illuminate a ‘black hole’ where it is impossible to receive broadcast signals. The system would receive signals off-air, pass them through a low cost echo canceller and then re-transmit the signal. The echo canceller must remove unwanted signals received from the repeater’s own transmitter. Of key importance is the system’s ability to discriminate between the wanted and unwanted received signals and to remove the unwanted signal with minimal impact on the quality of the retransmitted signal.

The measurable objectives of the repeater part of the project will be to;

1. Characterise typical signal conditions for DVB and DAB with field measurements.
2. Explore effectiveness of feed-forward algorithms to cancel the echoes.
3. Identify with software models the best-case modulation error rate that can be achieved for the retransmitted signal.
4. Produce experimental equipments for use in lab simulations and field trials and future productisation

iii. MultiChannel Power Amplification (MCPA)

MCPA amplifiers would allow multiple RF channels to be passed through a single amplifier. Broadcast sites generally transmit several channels and employ separate transmit chains for each channel leading to complex and expensive installations. A small repeater would also traditionally employ several separate receive and transmit chains and if diversity is implemented then this complexity would be doubled. Combining therefore a multi channel amplifier with a multichannel echo canceller would provide extensive cost, complexity and size advantages. Additionally since in traditional architectures splitting and combining can degrade carrier to noise of the resultant retransmitted signal there could be performance advantages of a new integrated architecture. It is only due to recent advances in technology that these concepts can potentially be implemented.

Measurable objectives of this part of the program will be to;

1. Identify through modelling the best architecture to simplify and reduce costs for repeaters.
2. Identify the relationship between output power, bandwidth and distortion to determine the maximum bandwidth at which these techniques can be implemented.
3. Produce experimental equipment for use in lab simulations and field trials and future productisation.

iv. Network Modelling

Once the effects of these techniques have been evaluated their impact on network design and cost of network roll-out will be evaluated. Example networks will be designed using both the traditional broadcast model of few large high power transmitters and the cellular model of many small lower power transmitters with and without the diversity and repeaters. Networks will be designed for a variety of scenarios including extreme rural, mountainous and urban regions. Based on previous works [18-20], the impact on the indoor penetration will be assessed. Costs and complexity of each network design will be investigated and published in a reference document. The measurable objectives of this work will be:

1. Effectiveness of transmit diversity measured as a diversity gain and published in network design guidelines.
2. Effectiveness of mini on-channel repeaters compared to traditional repeaters measured in terms of network coverage and use of spectrum.
3. Comparison of modelled network costs with and without transmitters and repeaters.
4. Produce and publish network design guidelines.
5. Produce engineering rules and recommendation for a modified Radio Planning tool for use in future network design.

v. Network Management and Service Creation

A further objective of the work will be to investigate how a service management system should be enhanced to enable handover of mobile broadcast multimedia services between technologies such as 3G and DVB and between transmitters. It is postulated for this project that the decision of a terminal to select a particular broadcast service over a particular access medium depends on not just current network connectivity but also on estimated robustness for a particular type of mobility and reception scenario. It is envisaged that network descriptors and end-to-end QoS agents will be required to access and report on low level quality of service data from end-user terminals.

This will be carried out as an extension to the work conducted for the INSTINCT project in which the system measures quality of current network connectivity. Terminal platforms access the EPGs/ESGs to filter out any services that cannot be accessed due to insufficient network connectivity, terminal media playing capability or network area locality. The EPG/ESG standard currently being jointly developed by DVB-IPDC and TVAnytime, allows any terminal using any API to parse the EPG/ESG and determine which services it is able to access, based on its own known network connectivity, position (Galileo), player capability and network area location.

Measurable objectives for this part of the program will be;

1. Define in engineering terms, service scenarios that describe the future use of broadband services in terms of service type (TV, Info systems, Entertainment, Gaming etc) and reception conditions (indoors, outdoors, mobile, walking, driving, urban, rural, mountainous etc).
2. Identify information that could be used to improve estimation of robustness by the terminal relating to suitability of network coverage for a particular scenario and improve the DVB-IPDC EPG/ESG description of networks to communicate this to terminals.
3. Prove through simulations that postulated network management handover algorithms are effective at enabling the user terminal to select between horizontal access technologies for particular service and reception scenarios.

III. FIELD TEST ENVIRONMENT

TDF have a complete test platform called PLASMA located near its research centre C2R in the city of Metz, this includes access to several test sites in a number of different locations and will be used for most of the field measurements. The platform is currently in use for IST projects INSTINCT and DAIDALOS for DVB-T and DVB-H tests purposes. The platform provides different kinds of transmitting sites and receiving environments to test the efficiency of different diversity transmission scenarios:

- **Luttange site (235 m height, mast high power TV)**

  Antenna array (5 individual UHF H antennas interconnected) located at 135m, with possibility to add an additional diversity antenna in either the vertical (range ±30 m) or horizontal (range ±5m) planes. The nearby coverage zone is mostly rural hilly and forests.

- **St Julien site (60 m height, mast small power TV)**

  2 UHF antennas located at the top in vertical and horizontal polarisation, separated by 3 m distance. Nearby coverage zone is suburban.

- **Scy Chazelles site (on a hill 200m above the city of Metz, 30 m height, medium power TV)**

  1 single V antenna installed with room to add additional diversity antennas in either vertical (range ±5 m) or horizontal (range ±5m) planes. This site is ideal for urban coverage as it dominates the city of Metz.

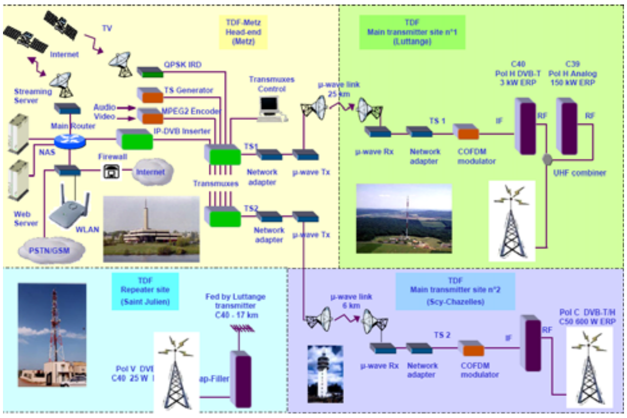

Figure 1: PLASMA Test Platform

All these sites have UHF DVB-T transmitters installed with remote micro-wave feeds and have transmission licences to broadcast any non commercial TV program or test signal. A DAB band III or L band small power transmitter or UMTS 3G node B could also be installed on one of the 2 latter sites, after application for an experimental licence.

A further site will be provided if required at a test site in a nearby mountainous region (Vosges at 100 km south) to assess diversity transmission efficiency in reception situations with strong echoes caused by the terrain. TDF will also provide a van equipped for monitoring purposes with test receivers and with a telescopic mast to assess fixed mode or mobile reception.

Receiving facilities will also be installed on some fixed places to monitor performances over a long period of time with remote retrieval of measured data.

IV. TECHNOLOGICAL APPROACH

This project will be addressed in four overlapping phases with completion of the overall program in 30 months.
In the first phase it is intended to conduct theoretical modelling into each aspect of the research. The largest activity in this phase will to model candidate diversity schemes using software, identifying the effectiveness of different techniques and guiding the team as to which should be investigated further. Other aspects of the research will be modelled by are MCPA's, echo cancellers and network selection.
In the second phase experimental equipment will be developed and assembled for lab testing. Brunel's test bed will be enhanced to enable laboratory simulations to be performed enabling research into how the candidate diversity signals can be effectively generated and to examine under controlled conditions how a state of the art receiver will process the diversity signals. During this phase simulation equipment will also be taken to testing laboratories to test for backwards compatibility with the many types of receiver already in service and experimental measurement receivers and repeaters will be fully characterised.
In phase three, once the optimum diversity scheme has been identified and proven in the lab, equipment will be installed in a number of Pilot trials. During this phase we will be able to conduct research to identify the optimal spatial separation to achieve decorrelated fading and to confirm the results of simulations with practical measurements in all possible reception scenarios. The experimental repeaters and receivers will also be fully tested in field conditions.
Finally the demonstration phase four will be undertaken to showcase the findings to the broadcast industry.

V. EXPECTED IMPACT on STANDARDISATION

The PLUTO project has a key role on influencing the broadcast industry and its standardisation bodies. Since diversity transmission is a relatively unknown technology within the broadcast industry much work will be done to disseminate its benefits to the different standardisation groups. Areas that will be affected relate to radio propagation models, network design and service management.
The first priority is to disseminate the technology in DVB-TM by presenting the project scope and objectives and then demonstrating the project results in the form of papers generated from project deliverables. The objective is to

establish diversity transmission as a work item for standardisation within DVB-TM covering;

- Diversity Transmission
- Radio Planning tools taking diversity and gap fillers into account

The second priority is to make the other main standardisation groups (ITU) aware of the technological developments undertaken in the project. The possible targeted groups could be ITU-R Study Groups 6 (Broadcasting Services) and 8 (Mobile services) as well as within Study Group 9 of ITU-T (Integrated broadband cable networks and television and sound transmission). The message that will be communicated is;

"Diversity transmission is a useful technology which holds a lot of promise for saving valuable spectrum and reducing the roll-out cost of DVB networks and which we are trying to establish as a work item within DVB-TM. We think you should be aware of this".

This same dissemination task will be extended to include international initiatives such as DigiTAG, the MHP Automotive Forum, 3GPP, TV-Anytime, etc as well organisations that represent and promote various sectors of industry such as the broadcast industry e.g.EBU EICTA or SMPTE, DTG etc.

The third priority is to disseminate the scope, objectives and outcomes of the project at workshops, conferences and trade shows. Both presentations and demonstrations will be made because diversity transmission technology has to be "seen to be believed". The targeted workshops will be the EU concertation meetings, IST summits and conferences. The results of the project will also be exhibited at one or more of the following trade shows: NAB (National Association of Broadcasters) Show and Convention at Las Vegas, the IBC (International Broadcasting Convention) at Amsterdam, the International TV Symposium at Montreux. An exhibit will be arranged at either IBC, IFA or SYSTEMS.

VI. CONCLUSIONS

The European IST FP6 PLUTO project focuses on improving the reception of wireless broadcast transmitted data by transmit diversity techniques and low cost on-channel repeaters.

The PLUTO consortium is balanced having expertise on all relevant aspects enhancing the existing broadcast standards and thus the potential to research and develop key technologies for also for future broadcast standards.

VII. PARTNERS

The partners of the PLUTO project are: Brunel University, Broadreach Systems, SIRADEL, Tampere University of Technology, TDF, Ortikon Interactive, Digital TV Group, Dibcom, German Aerospace Center (DLR).

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